MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2022/2023

ENT3056 – ADVANCED FABRICATION TECHNOLOGY

(NE)

8 JULY 2023
9.00 a.m. – 11.00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 7 pages with 4 Questions only.
2. Attempt **ALL FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.
4. Please refer to APPENDIX at page 6 and 7 for a list of physical constants, a list of formulas, and the error function table.

QUESTION 1

(a) The Czochralski method (Cz) is the most important method for the production of bulk single crystals of a wide range of electronic and optical materials.

(i) Illustrate the Cz process in a single crystal grower. [4 marks]
(ii) Describe the rotation mechanisms of the seed shaft and the Cz crucible. Explain the effect of such rotation on the physical properties of the single crystal grown using this technique. [3 marks]

(b) A boule of silicon (Si) rod is pulled from the melt mixed with boron (B) dopant. The wafer sliced out from the top of the boule has a dopant concentration of 1×10^{16} cm^{-3}. What is the doping concentration of the wafer taken from a position corresponding to 30 % of the initial charge solidified? The segregation coefficient (k) for B is 0.8. [4 marks]

(c) Silicon-on-insulator (SOI) technology deploys a layered silicon-insulator-silicon substrate in place of conventional silicon substrates in microelectronic manufacturing, to reduce parasitic device capacitance and improve performance. Describe the three methods in realizing SOI wafers. [6 marks]

(d) With the aid of a schematic diagram, describe the working mechanisms of a magnetron sputtering deposition process. [8 marks]

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QUESTION 2

(a) Describe the significance of the "doping process" in the semiconductor production. Differentiate the three types of semiconductor materials; *Intrinsic Semiconductor*, *Extrinsic Semiconductor*, and *Degenerate Semiconductor*. [8 marks]

(b) Identify the doping technique for the doping process characteristics given in Table 2(b). [7 marks]

Table 2(b)

Process Characteristics	Thermal Diffusion/Ion Implantation
High Temperature	
Isotopic Dopant Profile	
Anisotropic Dopant Profile	
Chemical Process	
Physical Process	
Ultrathin Junction	
Low Dopant Concentration Control	

(c) Describe the impact of the ion channeling in an ion implantation process. Identify the techniques used to overcome the ion channeling issue in the implantation doping of microelectronic fabrication. [4 marks]

(d) A cross-section of an NPN bipolar transistor realized using a thermal diffusion doping process is given in Figure 2(d). The doping concentration for the n-type Si substrate is given as $10^{14}cm^{-3}$. To form the p-well, the boron (B) dopants are doped into the Si substrate using the drive-in diffusion process at a temperature of 1100 °C for 70 minutes. The B dopant concentration at the surface of the Si substrate at the end of the doping process is given as $10^{17}cm^{-3}$. The diffusivity of B dopants in the Si substrate is $3 \times 10^{-15}cm^2s^{-1}$ at 1100 °C. Determine the dose of the B atoms for the drive-in diffusion process, in cm^{-2}, and the junction depth. [4 marks]

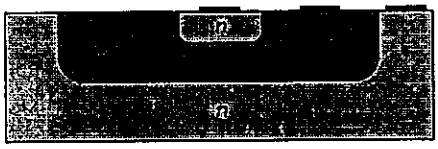

Figure 2(d): Cross-section of a NPN bipolar transistor.

(e) Assume that a 20 keV ion implantation is deployed to form the p-well in Figure 2(d). The projected range of the implanted profile is 900 Å and the standard deviation of the projected range is 100 Å. Determine the depth of peak of the implanted region and the peak concentration for an implantation dose of 9×10^{16} cm^{-2}. [2 marks]

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QUESTION 3

(a) Photolithography patterning is a crucial step in the microelectronic device processing. Describe the advantages of the projection printing method for photolithography patterning. [2 marks]

(b) In a photolithography patterning process, a deep ultraviolet (DUV) excimer laser system uses an exposure light source with a wavelength of 248 nm. The standard photoresist thickness achieved with the spin coater is 1.2 μm and assume a photoresist constant of 0.8. Determine the minimum feature size, W_{min}, that can be achieved using a proximity printing method with an air gap of 30 μm. [2 marks]

(c) Using negative photoresist as a sacrificial layer, design a lift-off process to realize the following metal pattern on a growing silicon substrate given in Figure 3(c). Describe the scenario when the lift-off method is necessary in patterning the metal. Give one example of the metal suitable for the lift-off method. [6+2 marks]

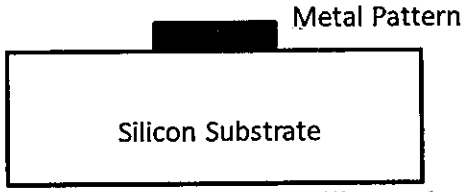

Figure 3(c): Metal pattern on a silicon substrate.

(d) Figure 3(d) shows the schematic cross-section of a hydrogen sensor based on field effect transistor (FET) with a hydrogen sensitive carbonaceous film containing Pd nanocrystallites (C–Pd layer). Design the fabrication process for the FET sensor by sketching the cross-sectional structure upon each of the process step, starting from the p-Si substrate. Label the structures and briefly state the respective processes. Identify the number of the photomask required in the fabrication process. [12+1 marks]

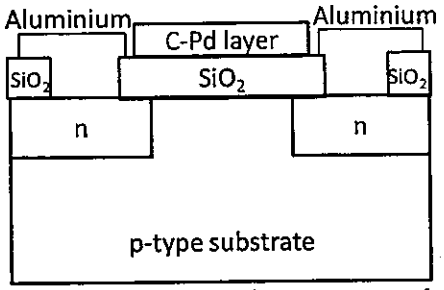

Figure 3(d): Schematic cross-section of a hydrogen sensor based on FET with a C-Pd layer.

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QUESTION 4

(a) Describe *SIX* (6) essential requirements for metallization in integrated microelectronic devices. [6 marks]

(b) Describe the advantages of copper (Cu) in Ultra Large Scale Integration (ULSI) metallization scheme compared to other available metallization materials such as aluminum and tungsten. Discuss the main issue of the Cu metallization scheme and propose a solution to address the issue. [6 marks]

(c) A metallization scheme with tungsten (W) (with resistivity, $\rho = 5\ \mu\Omega$-cm) metal layer is replaced with aluminum (Al) (with resistivity, $\rho = 2.6\ \mu\Omega$-cm) metal layer on silicon oxide (SiO_2) (with dielectric constant, $k = 3.9$) gate dielectric. Determine the percentage of reduction in the resistance-capacitance (R-C) time constant delay with the replacement of the new Al metallization scheme.

[2 marks]

(d) Determine the thickness of a tantalum silicide (TaSi) film for a measured sheet resistance of 1 ohm/square. The resistivity of the TaSi film is 100 μohm-cm.

[3 marks]

(e) Figure 4(e) depicts a cross section of a metal-oxide-semiconductor (MOS) device. Describe the function of the Pd_2Si, MSi_2, TiW, n^+ layer, AlCu in the MOS device, respectively.

[8 marks]

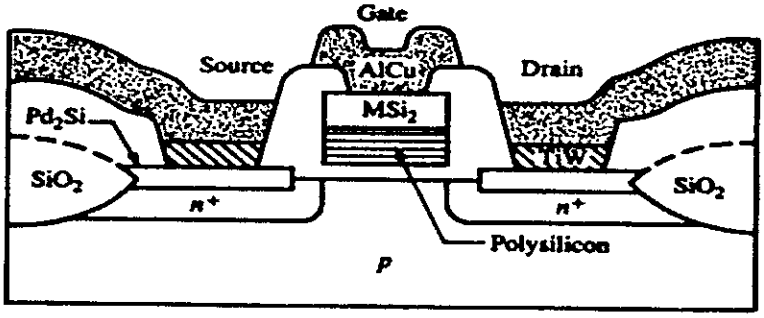

Figure 4 (e): Cross section of a CMOS inverter.

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APPENDIX (Physical Constants):

Avogadro number, $N_{avo} = 6.02217\times10^{23}$ mol^{-1}
Boltzmann constant, $k = 1.380622\times10^{-23}$ J K^{-1} = 8.61712×10^{-5} eV K^{-1}
Electronic charge, $e = 1.60219\times10^{-19}$ C
Electron rest mass, $m_o = 9.10956\times10^{-31}$ kg
Electron volt, 1 eV = 1.60219×10^{-19} J
Si yield strength = 2×10^{7} dynes cm = 7 GPa
Latent heat of fusion for Si, L = 340 cal g^{-1}
Thermal conductivity of Si, k = 0.21 W cm^{-1} °C^{-1}
Amount of heat of 1 calorie = 4.14 J
Density of bulk Si = 2.33 g cm^{-3}
Density of molten Si = 2.53 g cm^{-3}
Electric current of 1 A = 1 Cs^{-1}
Atomic mass unit of 1 amu = 1.66053×10^{-27} kg
Magnetic flux density of 1 T = 1 Wb m^{-2} = 10^4 G
Angstrom unit of 1 Å = 1×10^{-10} m = 0.1 nm = 1×10^{-4} μm
Permittivity of free space = 8.85×10^{-14} F cm^{-1}
Pressure of 1 Torr = 133.32237 Pa

Formulas:

$X_j = R_P \pm \Delta R_P \sqrt{2\ln(N_P/N_B)}$	$N(x) = \frac{Q_o}{\sqrt{2\pi}\Delta R_p} e^{\left[-\frac{1}{2}\left(\frac{x-R_p}{\Delta R_p}\right)^2\right]}$
$x_j = 2\sqrt{Dt\ \ln(N_0/N_B)}$	$N(x,y) = \frac{N(x)}{\sqrt{2\pi}\Delta R_\perp} e^{\left[-\frac{y^2}{2\Delta R_\perp{}^2}\right]}$
$x_j = 2\sqrt{Dt}\ erfc^{-1}(N_B/N_o)$	$C_s = \frac{Q}{\sqrt{\pi Dt}}$
$RC = \frac{R_s L^2 \in_{gd}}{d_{gd}} = \frac{\rho}{d_{poly-si}} \frac{L^2 \in_{gd}}{d_{gd}}$	$Q = 2C_s\sqrt{\frac{Dt}{\pi}}$
$C(x,t) = C_s erfc\left[\frac{x}{2\sqrt{Dt}}\right]$	$Q = \sqrt{2\pi} N_p \Delta R_p$
$C(x) = \frac{Q}{\sqrt{\pi Dt}} e^{-\left(\frac{x}{2\sqrt{Dt}}\right)^2}$	$C = k\,C_0\,(1-x)^{k-1}$
$W_{min} = k\{\lambda / NA\}$	$W_{min} = \sqrt{k\lambda g}$
$R_c = \rho_c / A, \quad \rho = R_s \cdot t,$ $\rho = 2\pi s\left(V/I\right)$	$k_0 = \frac{C_s}{C_l}$

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Values of the error function $\operatorname{erf}(t) = \frac{2}{\sqrt{\pi}} \int_0^t e^{-a^2} da$

t	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.0113	0.0226	0.0338	0.0451	0.0564	0.0676	0.0789	0.0901	0.1013
0.1	0.1125	0.1236	0.1348	0.1459	0.1569	0.1680	0.1790	0.1900	0.2009	0.2118
0.2	0.2227	0.2335	0.2443	0.2550	0.2657	0.2763	0.2869	0.2974	0.3079	0.3183
0.3	0.3286	0.3389	0.3491	0.3593	0.3694	0.3794	0.3893	0.3992	0.4090	0.4187
0.4	0.4284	0.4380	0.4475	0.4569	0.4662	0.4755	0.4847	0.4937	0.5027	0.5117
0.5	0.5205	0.5292	0.5379	0.5465	0.5549	0.5633	0.5716	0.5798	0.5879	0.5959
0.6	0.6039	0.6117	0.6194	0.6270	0.6346	0.6420	0.6494	0.6566	0.6638	0.6708
0.7	0.6778	0.6847	0.6914	0.6981	0.7047	0.7112	0.7175	0.7238	0.7300	0.7361
0.8	0.7421	0.7480	0.7538	0.7595	0.7651	0.7707	0.7761	0.7814	0.7867	0.7918
0.9	0.7969	0.8019	0.8068	0.8116	0.8163	0.8209	0.8254	0.8299	0.8342	0.8385
1.0	0.8472	0.8468	0.8508	0.8548	0.8586	0.8624	0.8661	0.8698	0.8733	0.8768
1.1	0.8802	0.8835	0.8868	0.8900	0.8931	0.8961	0.8991	0.9020	0.9048	0.9076
1.2	0.9103	0.9130	0.9155	0.9181	0.9205	0.9229	0.9252	0.9275	0.9297	0.9319
1.3	0.9340	0.9361	0.9381	0.9400	0.9419	0.9438	0.9456	0.9473	0.9490	0.9507
1.4	0.9523	0.9539	0.9554	0.9569	0.9583	0.9597	0.9611	0.9624	0.9637	0.9649
1.5	0.9661	0.9673	0.9684	0.9695	0.9706	0.9716	0.9726	0.9736	0.9746	0.9755
1.6	0.9764	0.9772	0.9780	0.9789	0.9796	0.9804	0.9811	0.9818	0.9825	0.9832
1.7	0.9838	0.9844	0.9850	0.9856	0.9861	0.9867	0.9872	0.9877	0.9882	0.9886
1.8	0.9891	0.9895	0.9899	0.9904	0.9907	0.9911	0.9915	0.9918	0.9922	0.9925
1.9	.99279	.99309	.99338	.99366	.99392	.99418	.99443	.99466	.99489	.99511
2.0	.99532	.99552	.99572	.99591	.99609	.99626	.99642	.99658	.99673	.99688
2.1	.99702	.99715	.99728	.99741	.99753	.99764	.99775	.99785	.99795	.99805
2.2	.99814	.99822	.99831	.99839	.99846	.99854	.99861	.99867	.99874	.99880
2.3	.99886	.99891	.99897	.99902	.99906	.99911	.99915	.99920	.99924	.99928
2.4	.99931	.99935	.99938	.99941	.99944	.99947	.99950	.99952	.99955	.99957
2.5	.99959	.99961	.99963	.99965	.99967	.99969	.99971	.99972	.99974	.99975
2.6	.99976	.99978	.99979	.99980	.99981	.99982	.99983	.99984	.99985	.99986
2.7	.99987	.99987	.99988	.99989	.99989	.99990	.99991	.99991	.99992	.99992
2.8	.99992	.99993	.99993	.99994	.99994	.99994	.99995	.99995	.99995	.99996
2.9	.99996	.99996	.99996	.99997	.99997	.99997	.99997	.99997	.99997	.99998
3.0	.99998	.99998	.99998	.99998	.99998	.99998	.99998	.99999	.99999	.99999

for $t > 3$ $\operatorname{erf}(t) \approx 1 - \frac{1}{\sqrt{\pi}\, t} \exp(-t^2)$

For Complementary Error Function, erfc (t) = 1 - erf (t)

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